#19/Trans.
Marsha
9/7/01

VERIFIED TRANSLATION

I, Yutaka OSAWA, residing at c/o Osawa Patent Office, 818, Ikebukuro White House Building, 20-2, Higashi-Ikebukuro 1-chome, Toshima-ku, Tokyo, Japan, do hereby declare that I am familiar with the English and Japanese languages and that the annexed document in the English language is a full and faithful translation, prepared by me, of a certified copy of Japanese Patent Application No. 8-115897 filed on May 10, 1996.

Dated this 17th day of August, 2001

Yutaka Osawa

Yutaka OSAWA

PATENT OFFICE
JAPANESE GOVERNMENT



This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: May 10, 1996

Application Number: Patent Application No. 8-115897

Applicant: CITIZEN WATCH CO., LTD.

May 23, 1997

Commissioner,
Patent Office Hisamitsu ARAI (sealed)

Certified Number 09-3037914

| | |
|---|---|
| [Name of Document] | Patent Application |
| [Case Number] | P-22838 |
| [Filing Date] | May 10, 1996 |
| [Addressee] | Commissioner of Patent Office<br>Yuji KIYOKAWA |
| [International Patent Classification] | G02F 1/133 |
| [Title of the Invention] | LIQUID CRYSTAL SHUTTER AND METHOD OF DRIVING THE SAME |
| [Number of Claims] | 8 |
| [Inventor] | |
| [Address or Residence] | c/o Citizen Watch Co., Ltd.<br>Technical Laboratory<br>840, Aza-Takeno, Oaza-Shimotomi,<br>Tokorozawa-shi, Saitama |
| [Name] | Yasushi KANEKO |
| [Inventor] | |
| [Address or Residence] | c/o Citizen Watch Co., Ltd.<br>Technical Laboratory,<br>840, Aza-Takeno, Oaza-Shimotomi,<br>Tokorozawa-shi, Saitama |
| [Name] | Masaaki MATSUNAGA |
| [Applicant for Patent] | |
| [Code Number] | 000001960 |
| [Postal Code] | 163-04 |
| [Name or corporation name] | CITIZEN WATCH CO., LTD. |
| [Representative] | Michio NAKAJIMA |
| [Telephone Number] | 03-3342-1231 |
| [Indication of Charge] | |
| [Prepayment Table Ledger Number] | 003517 |
| [Amount of Payment] | 21,000 |
| [List of Filed Documents] | |
| [Name of Document] | Specification 1 |
| [Name of Document] | Drawing 1 |
| [Name of Document] | Abstract 1 |
| [Confirmation of Proof] | Proof Necessary |

[NAME OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] LIQUID CRYSTAL SHUTTER AND METHOD OF DRIVING THE SAME

[CLAIMS]

[Claim 1] A liquid crystal shutter comprising: a liquid crystal device comprising a first substrate having a first electrode, a second substrate having a second electrode, and nematic liquid crystal having a twist angle equal to or greater than 180° and sandwiched between the first substrate and the second substrate; and a pair of polarizing plates between which the first substrate and the second substrate are sandwiched, wherein absorption axes of the polarizing plates are orthogonal to each other, and the absorption axes of the polarizing plates are angled at about ±45° relative to a direction in which intermediate liquid crystal molecules of the liquid crystal device are oriented.

[Claim 2] A liquid crystal shutter comprising: a liquid crystal device comprising a first substrate having a first electrode, a second substrate having a second electrode, and nematic liquid crystal having a twist angle equal to or greater than 180° and sandwiched between the first substrate and the second substrate; and a pair of polarizing plates between which the first substrate and the second substrate are sandwiched, wherein absorption axes of the polarizing plates are orthogonal to each other, and $\Delta nd$ lies within a range of 600 to 900 nm, said $\Delta nd$ being a product of a birefringence $\Delta n$ of the nematic liquid crystal and a gap d between the first substrate and the second substrate.

[Claim 3] A liquid crystal shutter comprising: a liquid crystal device comprising a first substrate having a first electrode, a second substrate having a second electrode, and nematic liquid crystal having a twist angle equal to or greater than 180° and sandwiched between the first substrate and the second substrate; and a pair of polarizing plates between which the first substrate and

the second substrate are sandwiched, wherein absorption axes of the polarizing plates are orthogonal to each other, the absorption axes of the polarizing plates are angled at about ±45° relative to a direction in which intermediate liquid crystal molecules of the liquid crystal device are oriented, and Δnd lies within a range of 600 to 900 nm, said Δnd being a product of a birefringence Δn of the nematic liquid crystal and a gap d between the first substrate and the second substrate.

[Claim 4] A method of driving the liquid crystal shutter according to claim 1, 2 or 3, wherein a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, and a duration of the scan term is made shorter than a holding time taken for a transmittance of the liquid crystal shutter to start to lower after it has reached its maximum.

[Claim 5] A method of driving the liquid crystal shutter according to claim 1, 2 or 3, wherein a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, a gradation display is performed by varying a period during which 0 V is set in the scan term, and a duration of the scan term is made shorter than a holding time taken for a transmittance of the liquid crystal shutter to start to lower after it has reached its maximum.

[Claim 6] A method of driving the liquid crystal shutter according to claim 1, 2 or 3, wherein a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, a gradation display is performed by varying a voltage applied in

the scan term from 0 V, and a duration of the scan term is made shorter than a holding time taken for a transmittance of the liquid crystal shutter to start to lower after it has reached its maximum.

[Claim 7] A method of driving the liquid crystal shutter according to claim 1, 2 or 3, wherein a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, a duration of the scan term is made shorter than a holding time taken for a transmittance of the liquid crystal shutter to start to lower after it has reached its maximum, and the frame term is controlled depending on an operating temperature such that the frame term is increased in the case of low temperature and reduced in the case of high temperature.

[Claim 8] A method of driving the liquid crystal shutter according to claim 1, 2 or 3, wherein a frame term which is a single drive term is composed of a scan term during which predetermined pixels are rendered opened, closed or half-opened, and the frame term is controlled depending on an operating temperature such that the frame term is increased in the case of low temperature and reduced in the case of high temperature.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[TECHNICAL FIELD OF THE INVENTION]

The invention relates to a liquid crystal shutter for use in a liquid crystal optical printer and a liquid crystal optical device, characterized in fast response, and a method of driving the liquid crystal shutter.

[0002]

[BACKGROUND TECHNOLOGY]

Requirements for a liquid crystal shutter for use in a liquid crystal

printer or a liquid crystal optical device are a rapid response, a bright display, a high contrast and a simple driving method, as well as a possible gradation display. However, a liquid crystal shutter satisfying all these requirements has not been developed so far.

[0003]

The liquid crystal shutters which have hitherto been developed are roughly grouped into the following categories by liquid crystal materials used: (1) one using a general nematic liquid crystal; (2) one using a nematic liquid crystal for two-frequency driving method having a positive or negative dielectric constant depending on the frequencies; and (3) one using a ferroelectric liquid crystal having a spontaneous polarization.

[0004]

The liquid crystal shutter using the two-frequency driving method mentioned above (2) has a rapid response but has a complicated driving circuit due to its high driving voltage and high driving frequency. The liquid crystal shutter using the ferroelectric liquid crystal mentioned above (3) operates faster than that using the two-frequency driving liquid crystal, that is, with a response time of several tens of μs, but is deficient in the stability of orientation due to use of a smectic liquid crystal phase. It also brings about a sticking phenomenon in which a display pattern remains fixed due to the DC drive and entails in principle a difficulty with the gradation control, which prevent it from being put to practical use except in certain specific applications.

[0005]

On the other hand, as the liquid crystal shutter using the general nematic liquid crystal mentioned above (1), the following systems are known depending on the principle of operation: (a) a so-called TN (twisted nematic)

liquid crystal system in which a white or black display is performed by utilizing a phenomenon called rotary polarization, rotating the incident light, in which a black or white display is performed by applying a voltage to pixels so as to orientate the liquid crystal molecules substantially orthogonal to the substrates to thereby eliminate the rotary polarization; and (b) a so-called STN (super twisted nematic) liquid crystal system in which a white or black display is performed by utilizing birefringence causing a phase difference in the incident light, in which a black or white display is performed by applying a voltage to the display pixels to thereby vary the birefringence.

[0006]

An example of the liquid crystal system of (a) is disclosed in JP, 62-150330, A. Reference is made to Figs. 10 and 11 to explain the conventional example. Fig. 11 is a sectional view of the conventional TN liquid crystal shutter, and Fig. 10 is a plan view showing a distribution of constituents when Fig. 11 is viewed from the upper polarizing plate 9 side. The liquid crystal shutter comprises: a liquid crystal device comprising a first substrate 1 on which are formed a first electrode 2 made of ITO and an orientation film 3, a second substrate 4 on which are formed a second electrode 5 made of ITO and an orientation film 6, and a nematic liquid crystal 7; and a lower polarizing plate 8 and an upper polarizing plate 9 which are disposed such that their respective absorption axes are orthogonal to each other. In this case, the liquid crystal device has a twisted angle of 90°, the absorption axis 13 of the lower polarizing plate is parallel to the direction 10 in which lower liquid crystal molecules are orientated, that is, the direction of orientation of the liquid crystal closer to the first substrate 1, and the absorption axis 14 of the upper polarizing plate is parallel to the direction 11 in which upper liquid crystal molecules are orientated, that is, the direction of orientation of the

liquid crystal closer to the second substrate 4.

[0007]

With no voltage applied, linearly polarized light transmitted through the lower polarizing plate 8 is rotated by 90° due to the rotary polarization of the liquid crystal and exits from the upper polarizing plate 9, resulting in an opened state allowing a so-called positive display. When a 15 V voltage is applied at a 5 kHz driving frequency, the liquid crystal molecules are orientated in the direction orthogonal to the substrates to nullify the rotary polarization, thus allowing the linearly polarized light transmitted through the lower polarizing plate 8 to advance intactly through the interior of the liquid crystal device without any rotation and to be blocked by the upper polarizing plate 9, resulting in a closed state.

[0008]

An example employing method (b) above includes an STN liquid crystal display device called a yellow-mode for use in general liquid crystal displays. A conventional example thereof will be described with reference to Figs. 12 and 13. Fig. 13 is a sectional view of a conventional STN liquid crystal display device, and Fig. 12 is a plan view showing a distribution of constituents when Fig. 13 is viewed from the upper polarizing plate 9 side. The liquid crystal display device comprises: a liquid crystal device comprising a first substrate 1 on which are formed a first electrode 2 made of ITO and an orientation film 3, a second substrate 4 on which are formed a second electrode 5 made of ITO and an orientation film 6, and a nematic liquid crystal 7; and a lower polarizing plate 8 and an upper polarizing plate 9 which are disposed such that their respective absorption axes intersect at 60° relative to each other. In this case, the liquid crystal device has a twisted angle of 240°, the absorption axis 13 of the lower polarizing plate is angled at

45° relative to the direction 10 in which the lower liquid crystal molecules are orientated, that is, the direction of orientation of the liquid crystal closer to the first substrate 1, and the absorption axis 14 of the upper polarizing plate is angled at 45° relative to the direction 11 in which the upper liquid crystal molecules are orientated, that is, the direction of orientation of the liquid crystal closer to the second substrate 6. Thus, relative to the direction 12 in which the intermediate liquid crystal molecules are orientated, that is, the direction of orientation of the liquid crystal molecules intermediate between the first substrate 1 and the second substrate 4, the absorption axis 13 of the lower polarizing plate forms an angle of 75°, and the absorption axis 14 of the upper polarizing plate forms an angle of 15°.

[0009]

With no voltage applied, linearly polarized light incident at 45° relative to the liquid crystal molecules through the lower polarizing plate 8 is turned into elliptically polarized light due to the birefringence of the liquid crystal, which in turn exits from the upper polarizing plate 9, resulting in an opened state allowing a yellowish white color display, that is, a so-called positive display. When 3 to 5 V voltage is applied at 1 to 5 kHz frequency, the liquid crystal molecules 7 are orientated in the direction orthogonal to the substrates to reduce its birefringence, thus allowing the linearly polarized light incident through the lower polarizing plate 8 to undergo a varied state of elliptical polarization, and in turn exits from the upper polarizing plate 9 allowing a bluish black display in the closed state.

[0010]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

In the case of system (a) above, however, the response time taken to return to the opened state by the removal of voltage from the closed state is as

long as ten to several tens of ms (milliseconds) although the response time taken to reach the closed state by the applying of voltage from the opened state is as short as several ms. Hence, the frame term must be increased corresponding to a write term during which opening and closing are repeated, resulting in an increased write time and a reduced print speed in a liquid crystal printer. It is also impossible to apply it to a high-speed liquid crystal optical device required to have a frame term of several ms.

[0011]

Furthermore, the above publication teaches that the liquid crystal device having a 270° or 450° twist other than a 90° twist is more preferred due to a reduction in the response time taken to recover the open state. Although it is certain that the 270° twist is shorter in response time than the 90° twist, a specific orientation film, such as SiO orthorhombic deposited film, ensuring a high pre-tilt must be used with a concurrent difficulty of obtaining satisfactory stability in orientation, which is not practical.

[0012]

In the case of system (b) above, the liquid crystal device can be employ a practical so-called STN liquid crystal device having a 225° to 250° twist, thereby reducing the response time from the closed state to the opened state to several ms. As a result of application of voltage to the liquid crystal device, however, the closed state presents a bluish black color and hence the contrast is as low as about 10. In addition, when the applied voltage is further raised, the state of the elliptically polarized light becomes changed, again allowing a brightening, so that the applied voltage cannot be set so high. It results in that the response time from the opened state to the closed state is increased to ten to several tens of ms, making it difficult to use it as a liquid crystal shutter.

[0013]

It is therefore the object of the present invention to provide a liquid crystal shutter ensuring a rapid response and a high contrast as well as a liquid crystal shutter driving method capable of a gradation display.

[0014]

[MEANS FOR SOLVING THE PROBLEMS]

In order to achieve the above object, the invention provides a liquid crystal shutter comprising a liquid crystal device comprising a first substrate having a first electrode, a second substrate having a second electrode, and nematic liquid crystal having a twist angle equal to or greater than 180° and sandwiched between the first substrate and the second substrate, and a pair of polarizing plates between which the first substrate and the second substrate are sandwiched, wherein absorption axes of the polarizing plates are orthogonal to each other, and the absorption axes of the polarizing plates are angled at about ±45° relative to a direction in which intermediate liquid crystal molecules of the liquid crystal device are oriented.

[0015]

The invention also provides a liquid crystal shutter comprising a liquid crystal device comprising a first substrate having a first electrode, a second substrate having a second electrode, and nematic liquid crystal having a twist angle equal to or greater than 180° and sandwiched between the first substrate and the second substrate, and a pair of polarizing plates between which the first substrate and the second substrate are sandwiched, wherein absorption axes of the polarizing plates are orthogonal to each other, and $\Delta nd$ lies within a range of 600 to 900 nm, said $\Delta nd$ being a product if a birefringence $\Delta n$ of the nematic liquid crystal and a gap d between the first substrate and the second substrate.

[0016]

The invention further provides a liquid crystal shutter comprising a liquid crystal device comprising a first substrate having a first electrode, a second substrate having a second electrode, and nematic liquid crystal having a twist angle equal to or greater than 180° and sandwiched between the first substrate and the second substrate, and a pair of polarizing plates between which the first substrate and the second substrate are sandwiched, wherein absorption axes of the polarizing plates are orthogonal to each other, the absorption axes of the polarizing plates are angled at about ±45° relative to a direction in which intermediate liquid crystal molecules of the liquid crystal device are oriented, and Δnd lies within a range of 600 to 900 nm, said Δnd being a product if a birefringence Δn of the nematic liquid crystal and a gap d between the first substrate and the second substrate.

[0017]

Further, the invention provides a method of driving the liquid crystal shutter wherein a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, and a duration of the scan term is made shorter than a holding time taken for a transmittance of the liquid crystal shutter to start to lower after it has reached its maximum.

[0018]

The invention also provides a method of driving the liquid crystal shutter wherein a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, a gradation display is performed by varying a period during which 0 V is set in

the scan term, and a duration of the scan term is made shorter than a holding time taken for a transmittance of the liquid crystal shutter to start to lower after it has reached its maximum.

[0019]

The invention further provides a method of driving the liquid crystal shutter wherein a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, a gradation display is performed by varying a voltage applied in the scan term from 0 V, and a duration of the scan term is made shorter than a holding time taken for a transmittance of the liquid crystal shutter to start to lower after it has reached its maximum.

[0020]

[OPERATION]

Reference is now made to Figs. 3 and 4 to describe the operations of the liquid crystal shutter according to the invention. A solid line 20 in Fig. 3 represents a voltage − transmittance curve showing change of transmittance relative to applied voltage of the liquid crystal shutter applied to the invention. A voltage − transmittance curve of a conventional yellow-mode STN liquid crystal display device is represented by a broken line 21 for comparison. Both of them are 240° twisted STN liquid crystal devices, $\Delta nd$ of them are 800nm, and only angles at which the polarizing plates cross each other and arrangement of the polarizing plates are different from each other. Absorption axes of a pair of upper and lower polarizing plates are orthogonal to each other in the liquid crystal shutter according to the invention. On the other hand, absorption axes of a pair of upper and lower polarizing plates cross each other at 60° in the conventional yellow-mode liquid crystal shutter,

and arranged as shown in Fig. 12.

[0021]

Both utilize birefringence of the liquid crystal device when no voltage is applied and in an opened state. However, the conventional yellow-mode one is colored yellow though the transmittance thereof is high, because the polarizing plates are arranged such that the birefringence is rendered higher in the conventional one. On the other hand, the liquid crystal shutter according to the invention is slightly colored yellow at the initial transmittance Y0 where no voltage is applied, because the liquid crystal shutter also utilizes the birefringence. However, when voltage is applied, the maximum transmittance is reached, the shutter becomes an almost achromatic color, and thereafter the transmittance reduces. This voltage – transmittance curve 20 is influenced by the arrangement of the polarizing plates, and bright and preferable characteristic can be obtained by optimizing the arrangement.

[0022]

Fig. 4 is a graph showing a relationship between the arrangement of the polarizing plate and the transmittance, determined by examination upon the liquid crystal device used in the liquid crystal shutter of the invention. A curved line 23 indicates the initial transmittance Y0 with no voltage applied when the absorption axis of the lower polarizing plate is rotated from the direction in which intermediate liquid crystal molecules at the center of the first substrate and the second substrate are orientated, while keeping the crossing angle of the absorption axes of the upper and lower polarizing plates at 90°, and a curved line 22 indicates the maximum transmittance Ym. By arranging the absorption axis of the lower electrode at ±45° relative to the direction in which intermediate liquid crystal molecules are oriented, the initial transmittance Y0 and the maximum transmittance Ym can be set most,

and it was found by measuring that the color is close to achromatic color, and bright and preferable characteristic can be obtained.

[0023]

Further, in the yellow-mode, black characteristic can be obtained by a low voltage of about 3 V because it utilizes the birefringence also in the closed state. However, the black is bluish, the transmittance is not completely lowered, and the contrast is low. When the voltage is further applied, the transmittance increases again and the contrast decreases more. Hence a high voltage can not be applied, and thus the response time taken from the opened state to the closed state can not be lowered.

[0024]

However, the liquid crystal shutter of the invention utilizes a state in which the liquid crystal devices are orientated in the direction nearly orthogonal to the substrates to nullify the birefringence, for the closed state. Hence a high contrast can be obtained and the response time taken from the opened state to the closed state can be rendered fast to equal to or less than 1ms, although a high voltage of equal to or higher than 10 V is needed.

[0025]

Further, the response time taken from the closed state to the opened state of the liquid crystal shutter of the invention is very faster than that of the conventional 90° twisted TN liquid crystal shutter utilizing rotary polarization, which is rendered to be 1 to 3 ms, and thus fast response becomes possible, because the liquid crystal device with liquid crystal twisted at equal to or greater than 180° is utilized in the shutter.

[0026]

Accordingly, in the invention, a liquid crystal shutter with high contrast and fast response can be provided by utilizing liquid crystal device

twisted at equal to or greater than 180°, utilizing birefringence for the opened state, and utilizing a state in which the liquid crystal is orientated in the direction nearly orthogonal to the substrates to nullify the birefringence, for the closed state.

[0027]

Next, operations of a method of driving a liquid crystal shutter according to the invention is described. The liquid crystal shutter according to the invention becomes a closed state in which a black display is performed from the initial transmittance Y0 with no voltage applied through the maximum transmittance Ym. Because the shutter is colored yellow in the initial transmittance Y0, it is not preferable to utilize this state for a gradation display.

[0028]

On the other hand, it was confirmed by experiment that the shutter returned to the initial transmittance Y0 after kept at the maximum transmittance Ym for a certain duration. Accordingly, if opening and closing are repeated within a holding time during which the state of the maximum transmittance Ym is held, the gradation display with no color and good linearity can be performed.

[0029]

Hence, by composing a frame term which is a single drive term is composed of a reset term during which all pixels are rendered closed and a scan term during which predetermined pixels are rendered opened, closed or half-opened, and making a duration of the scan term shorter than a holding time of the maximum transmittance Ym, and compulsory returning to the closed state in a reset term before returning from the maximum transmittance Ym to the initial transmittance Y0, a method of driving by which good

gradation display can be performed can be provided.

[0030]

[EMBODIMENTS FOR CARRYING OUT THE INVENTION]

(First Embodiment)

Hereinafter, a structure of a liquid crystal shutter and a method for driving the liquid crystal shutter in the preferred embodiment for carrying out the invention is described referring to figures.

[0031]

Fig. 2 is a sectional view showing a structure of a liquid crystal shutter according to a first embodiment of the invention, and Fig. 1 is a plan view showing a state in which Fig. 2 is viewed from the top side. Hereinafter, the structure of the liquid crystal shutter of the invention is described referring to Figs. 1 and 2 alternately.

[0032]

The liquid crystal shutter according to the embodiment comprises a first substrate 1 made of 0.7 mm-thick glass on which are formed a first electrode 2 made of ITO and an orientation film 3; a second substrate 4 made of 0.7 mm-thick glass on which are formed a second electrode 5 made of ITO and an orientation film 6; and a nematic liquid crystal 7, to constitute a liquid crystal device. The birefringence $\Delta n$ of the nematic liquid crystal used is 0.2, the gap d between the first substrate 1 and the second substrate 6 is 4 μm, and the value of $\Delta nd$ indicating a birefringence as a liquid crystal device is set at 800nm.

[0033]

The orientation film 3 on the first substrate 1 is previously subjected to a rubbing treatment in a direction 10 in which lower liquid crystal molecules are orientated, and the orientation film 6 on the second substrate 4

is previously subjected to the rubbing treatment in a direction 11 in which upper liquid crystal molecules are orientated, as illustrated in Fig. 1. To twist liquid crystal molecules, a rotating material called chiral material is added to the nematic liquid crystal having a viscosity of 18cp, allowing its natural twist pitch to be 8 μm, to thereby form a leftward 240° twisted liquid crystal device.

[0034]

On the top and bottom of the liquid crystal device, there are arranged an upper polarizing plate 9 and a lower polarizing plate 8, respectively, in such a manner that their respective absorption axes 14 and 13 are orthogonal to each other. At that time, the absorption axis 13 of the lower polarizing plate is angled at 45° counterclockwise relative to the direction 12 in which intermediate liquid crystal molecules are orientated, the direction 12 indicating the direction of orientation of the intermediate portion of the nematic liquid crystal 7 between the first substrate 1 and the second substrate 4, whereas the absorption axis 14 of the upper polarizing plate is angled at 45° clockwise relative to the direction 12 in which the intermediate liquid crystal molecules are orientated, thus constituting a positive liquid crystal shutter.

[0035]

In a state where no voltage is applied, linearly polarized light which has passed through the lower polarizing plate 8 is turned by the birefringence of the liquid crystal into an elliptically polarized light, which is then allowed to exit from the upper polarizing plate 9 to form a slightly yellowed white display at an opened state, indicationg a so-called positive display. When a DC or AC voltage of 10 to 20 V is applied, the liquid crystal molecules are orientated in the direction orthogonal to the substrates so that the birefringence is nullified, allowing linearly polarized light which has passed

through the lower polarizing plate 8 to travel intactly through the interior of the liquid crystal device to be blocked by the upper polarizing plate 9, thus forming a black display at a closed state.

[0036]

A solid line 20 in Fig. 3 represents a transmittance – voltage curve of the liquid crystal shutter of the invention. Starting from the initial transmittance Y0 with no voltage applied, the transmittance gradually rises, and reaches a maximum transmittance Ym in the vicinity of an applied voltage of 2 V, thereafter the transmittance lowers. The transmittance at an applied voltage of 10 V becomes about a fiftieth of the initial transmittance Y0, with a contrast ratio on the order of 50. Application of a higher voltage of 20 V results in the acquisition of a contrast ratio of equal to or more than 100.

[0037]

Since the opened state allowing the white display with no voltage applied is presented by making use of the birefringence of the liquid crystal device as described above, the arrangement of the polarizing plates and the setting of Δnd indicative of the birefringence of the liquid crystal device are essential, which affect the brightness and the colored state to large extent.

[0038]

Fig. 4 shows arrangement angles of the lower polarizing plate and the transmittance of the liquid crystal shutter, obtained when the lower polarizing plate 8 is rotated counterclockwise from the direction in which the intermediate liquid crystal molecules are orientated, with the intersection angle fixed at 90° between the absorption axis 13 of the lower polarizing plate and the absorption axis 14 of the upper polarizing plate in a 240° twisted liquid crystal device having a value of Δnd equal to 800nm. A solid line 22

represents a relationship between the maximum transmittance Ym and the arrangement angle of the polarizing plate, while a broken line 23 represents a relationship between the initial transmittance Y0, with no voltage applied, and the arrangement angle of the polarizing plate. At -60°, the direction 10 in which the lower liquid crystal molecules are orientated becomes parallel to the absorption axis 13 of the lower polarizing plate. It is most advantageous at -45° and +45° in that both Y0 and Ym present their respective local maximum values with less colored conditions.

[0039]

Fig. 5 shows Δnd of the 240° twisted liquid crystal device and the transmittance of the liquid crystal shutter, obtained when the absorption axis 13 of the lower polarizing plate is positioned at 45° counterclockwise from the direction 12 in which the intermediate liquid crystal molecules are orientated, with an intersection angle of 90° between the absorption axis 13 of the lower polarizing plate and the absorption axis 14 of the upper polarizing plate. A solid line 24 represents the maximum transmittance Ym and a broken line 25 represents the initial transmittance Y0 with no applied voltage. At Δnd = 650nm, the maximum transmittance Ym reaches its maximum and thereafter remains substantially unvaried even though Δnd further increases, whereas the initial transmittance Y0 with no applied voltage gradually lowers, so that it is not preferred for Δnd to become too large. On the contrary, when Δnd is smaller than 650nm, the maximum transmittance Ym also decreases, with the result that, a preferred value of Δnd lies within a range of 600nm to 900nm, and particularly 700nm to 800nm.

[0040]

Although the most preferable Δnd value may vary more or less depending on the twisted angle, the optimum value of Δnd lies within a range

of about 600nm to 900nm, in the case of a twisted angle of equal to or greater than 180° and equal to or less than 260°.

[0041]

In this embodiment, Δnd is set at 800nm with the twisted angle of 240°, so that the opened state ensuring a bright and relatively less colored white display is achieved with a contrast of more than 100 upon the application of a drive voltage of 20 V.

[0042]

Description will next be made of a method of driving the liquid crystal shutter of the invention. Fig. 6 is a diagram depicting a driving waveform 30 and a transmittance – time curve 31 representative of the variance with time of the transmittance, obtained when a 100 Hz, 20 V AC signal is applied for 50 ms. When the AC signal is applied under the opened state at no applied voltage, the transmittance instantaneously rises and thereafter becomes black display. An on-response time 26 is influenced by the applied voltage so that accordingly as a higher voltage is applied to the liquid crystal shutter, the on-response time 26 decreases. In this embodiment, the liquid crystal shutter is subjected to a high voltage of 20 V, thus achieving a very rapid on-response time 26 of less than one ms.

[0043]

On the contrary, when the AC signal is returned to 0 V under the closed state, the transmittance reaches its maximum in about two ms and recovers its initial value after an elapse of about 20 ms. Due to the utilization of a resilient force untwisting the liquid crystal twist, an off-response time for returning from the closed state to the opened state decreases accordingly as the twisted angle of the liquid crystal device increases. The proper definition of the response time for the liquid crystal device is the time

taken for the variance of the liquid crystal molecules to become stabilized. Hence, in Fig. 6, the response time is 20 ms. In the case of being used as the liquid crystal shutter, however, the time taken for the transmittance to return to the opened state allowing the white display is effective as the response time. Thus, the off-response time 27 of the 240° twisted liquid crystal shutter in accordance with the present invention is 2 ms, achieving a rapid response liquid crystal shutter.

[0044]

Until the maximum transmittance in the opened state is exhibited after the black display in the closed state, there is provided a relatively less colored and bluish white display. After the elapse of about 10 ms of a holding time 28 during which its maximum transmittance is kept, the transmittance lowers while being yellowed to some extent. In order to execute a gradation display, therefore, a reset signal is issued within the holding time 28 during which the liquid crystal shutter exhibits its maximum transmittance, to restore the closed state. Thus, by utilizing the less colored state between the closed state and the maximum transmittance, a satisfactory gradation display is achieved.

[0045]

Fig. 7 shows a driving waveform 32 and a transmittance – time curve 33, obtained when the liquid crystal shutter in accordance with the invention is applied to a color video liquid crystal printer. The reset term Tr is set to be 1 ms which is longer than the on-response time 26, and the scan term Ts is set to be 4 ms which is shorter than 10 ms of the holding time 28. A frame term Ts corresponds to a single write term, which consists of a reset term Tr and a scan term Ts, a first frame at the left-hand end of Fig. 7 indicates a fully-opened state, a second frame in the middle indicates a half-opened state, and a third frame at the right-hand end indicates a closed state.

[0046]

In the reset term Tr, to render all pixels closed, a 20 V DC signal is applied as a reset signal. In the case of rendering the liquid crystal shutter fully opened in the scan term Ts, as a scanning signal, 0 V is applied over the entire duration of the scan term Ts. In the scan term Ts when keeping the liquid crystal shutter closed, a 20 V signal is applied over the entire duration of the scan term Ts. In the case of making the liquid crystal shutter half-opened to present halftones in the scan term Ts, 0 V is applied for 2 ms equal to half of the scan term Ts and 20 V is applied for the remaining 2 ms.

[0047]

By inverting polarities of the reset signal and scanning signal between the first frame and the second frame, long-term DC voltage application to the liquid crystal device is suppressed. After the return of all the pixels of the liquid crystal shutter to their respective closed states in the reset term Tr, a period of time during which a 0 V is applied is varied in the scan term Ts so that only a predetermined pixel is opened or closed and an arbitrary gradation display is obtained.

[0048]

The scan term Ts is set at 4 ms, which is longer than 2 ms of the off-response time 27 taken to reach the maximum transmittance Ym after the closed state and is shorter than 10 ms of the holding time 28 taken to start to return to the initial transmittance Y0 from the maximum transmittance Ym, so that it is possible to obtain a liquid crystal shutter which can perform a gradation display subjected to less variation in color and having a good linearity, thus achieving the acquisition of a high-quality full color image print.

[0049]

Although this embodiment employs the 240° twisted liquid crystal device, any other liquid crystal device having a twist of equal to or greater than 180° is also applicable to obtain similar effects.

[0050]

It is sufficient if the absorption axes of the upper and lower polarizing plates intersect at approximately 90°, and it is possible that the arrangement angles of the polarizing plates lie within a range of 40° to 50° relative to the direction in which the intermediate liquid crystal molecules are orientated.

[0051]

Although in this embodiment the absorption axes of the polarizing plates are angled at ±45° relative to the direction in which the intermediate liquid crystal molecules are orientated and Δnd of the liquid crystal device is set at 800 nm, a certain effect is achieved merely by employing the ±45° arrangement of the polarizing plates or by setting Δnd of the liquid crystal device to 600 to 900 nm.

[0052]

Although in this embodiment such a description has been made that the gradation display is performed by varying the period of time during which 0 V is issued in the scan term 39, the gradation may be carried out by changing and increasing the voltage applied in the scan term from 0 V so as to increase the off-response time 27.

[0053]

(Second Embodiment)

Second method of driving the liquid crystal shutter which has the same structure as one used in the first embodiment will now be described as a second embodiment, with reference to Figs. 8 and 9.

[0054]

Fig. 8 is a diagram depicting a driving waveform 34 and a transmittance – time curve 35 at room temperature, obtained when the liquid crystal shutter of the invention is applied to a color video liquid crystal printer, and Fig. 9 is a diagram depicting a driving waveform 36 and a transmittance – time curve 37 at 0 °C. In Fig. 8, the reset term Tr at room temperature is set at 1 ms and the scan term Ts is set at 4 ms which is shorter than 10 ms of the holding time 28 taken for the transmittance to start to lower from the maximum transmittance Ym. A frame term Tf corresponds to a single write term, which consists of a reset term Tr and a scan term Ts. And in Fig. 8, a first frame at the left-hand end is in a fully opened state, the second frame adjacent on the right-hand side is in a half-opened state, the third frame which follows is in a closed state, and these frames are repeated twice.

[0055]

In the reset term Tr at room temperature, to render all pixels closed, positive and negative 20 V, 0.5 ms-long pulse waveforms are applied as reset signals in pairs. Scanning signals applied in the scan term Ts are set at 0 V throughout the scan term Ts in the case of making the liquid crystal shutter fully opened state. When keeping it closed state, they are fed in the form of 20 V, 0.5 ms-long pulse waveform signals throughout the scan term Ts. In the case of rendering it half-opened state to present halftones, they are set at 0 V for 2 ms equal to half of the scan term Ts but fed in the form of 20 V, 0.5 ms-long pulse waveform signals for the remaining 2 ms of the term.

[0056]

The reset signals and scanning signals are issued in the form of 0.5 ms-long pulse waveforms having positive and negative polarities so as to suppress long-term DC voltage application to the liquid crystal device. After the return of all the pixels of the liquid crystal shutter to their respective

closed states in the reset term Tr, a period of time during which 0 V is issued can be varied in the scan term Ts so that only a predetermined pixel is opened or closed, or an arbitrary gradation display is obtained.

[0057]

The scan term 39 at room temperature is set at 4 ms, which is longer than 2 ms of the response time taken to reach the maximum transmittance Ym from the closed state and shorter than 10 ms of the holding time 28 taken for the transmittance to return to the initial transmittance Y0 from the maximum transmittance Ym, so that it is possible to obtain a liquid crystal shutter which can perform a gradation display subjected to less variation in color and having a good linearity.

[0058]

A reduction in the temperature, however, results in an increased response time of the liquid crystal device. Since in particular the off-response time 27 from the closed state to the opened state increases, the brightness in the opened state is reduced, so that no opened state is exhibited at a further lowered temperature. In this embodiment, therefore, a temperature sensor is provided which, when the temperature goes down to 5 °C or below, automatically doubles the reset term Tr and the scan term Ts.

[0059]

Regarding the response time at 0 °C of the liquid crystal shutter in accordance with the invention, as is apparent from the transmittance − time curve 37 at 0 °C shown in Fig. 9, the on-response time 26 from open to close is 1.5 ms and the off-response time 27 from close to open is 4 ms, which are approximately twice as much as the respective response times at room temperature. At 0 °C, the holding time also approximately doubles, namely, increases to 20 ms. However, the drive waveform 36 at 0 °C has a 2 ms reset

term Tr and an 8 ms scan term Ts, which are rendered longer, thereby ensuring a satisfactory opened state.

[0060]

In the case where this liquid crystal shutter is applied to a liquid crystal printer, a high-quality full color image print can be obtained both at room temperature and 0 °C although the print speed at a low temperature is reduced to half of the print speed at room temperature.

[0061]

Although in the second embodiment of the invention, the frame term Tf consisting of the reset term Tr and the scan term Ts has been increased twice as much without varying the pulse length even at a low temperature, the pulse length may be simultaneously doubled to obtain exactly the same effect.

[0062]

In the case of not needing the halftone display, the frame term Tf may be composed of only the scan term Ts without the reset term Tr, instead of composing the frame term Tf of both the reset term Tr and the scan term Ts as in the second embodiment of the invention.

[0063]

Although in the second embodiment of the invention, such description has been made that the gradation control is carried out by varying the period of time during which 0 V is issued in the scan term 39, the gradation control may be performed by changing and increasing the voltage applied in the scan term from 0 V to thereby increase the off-response time.

[0064]

[EFFECT OF THE INVENTION]

As is apparent from the above description, by utilizing the liquid crystal shutter in accordance with the invention and the method of driving the

liquid crystal shutter ensures a realization of a bright and high contrast liquid crystal shutter in spite of rapid response, and a method of driving the liquid crystal shutter by which a gradation display also can be performed.

Further, by changing the duration of the frame term Tf depending on an operating temperature, a stable shutter characteristic can be maintained from a low temperature to a high temperature.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig.1]

A plan view showing adistribution in a liquid crystal shutter according to an embodiment of the invention.

[Fig.2]

A sectional view showing the liquid crystal shutter according to the embodiment of the invention.

[Fig. 3]

A graph showing an applied voltage – transmittance curve of the liquid crystal shutter according to the embodiment of the invention, and an applied voltage – transmittance curve of a conventional yellow-mode STN liquid crystal display device.

[Fig. 4]

A graph showing relationship between the arrangement of the polarizing plate and the transmittance in the embodiment of the invention.

[Fig.5]

A graph showing relationship between Δnd and the transmittance of the liquid crystal device according to the embodiment of the invention.

[Fig. 6]

A graph showing a driving waveform and a transmittance – time curve for explaining the embodiment of the invention.

[Fig. 7]

A graph showing a driving waveform and a transmittance – time curve of the liquid crystal shutter according to the first embodiment of the invention.

[Fig. 8]

A graph showing a driving waveform and a transmittance – time curve of the liquid crystal shutter according to the second embodiment of the invention at room temperature.

[Fig. 9]

A graph showing a driving waveform and a transmittance – time curve of the liquid crystal shutter according to the second embodiment of the invention at a low temperature.

[Fig. 10]

A plan view showing a distribution in a conventional TN liquid crystal shutter.

[Fig. 11]

A sectional view showing the conventional TN liquid crystal shutter.

[Fig. 12]

A plan view showing a distribution in a conventional STN liquid crystal display device.

[Fig. 13]

A sectional view showing the conventional STN liquid crystal display device.

[Reference of Numerals]

1 first substrate

2 first electrode

3 orientation film

4 second substrate

5 second electrode

6 orientation film

7 liquid crystal

8 lower polarizing plate

9 upper polarizing plate

10 direction in which lower liquid crystal molecules are orientated

11 direction in which upper liquid crystal molecules are orientated

12 direction in which intermediate liquid crystal molecules are orientated

13 absorption axis of lower polarizing plate

14 absorption axis of upper polarizing plate

26 on-response time

27 off-response time

28 holding time

32 driving waveform

33 transmittance – time curve

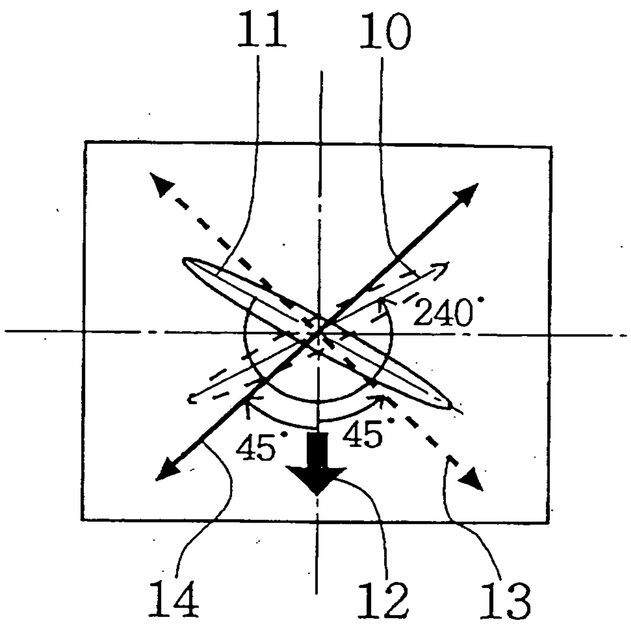
Tr reset term

Ts scan term

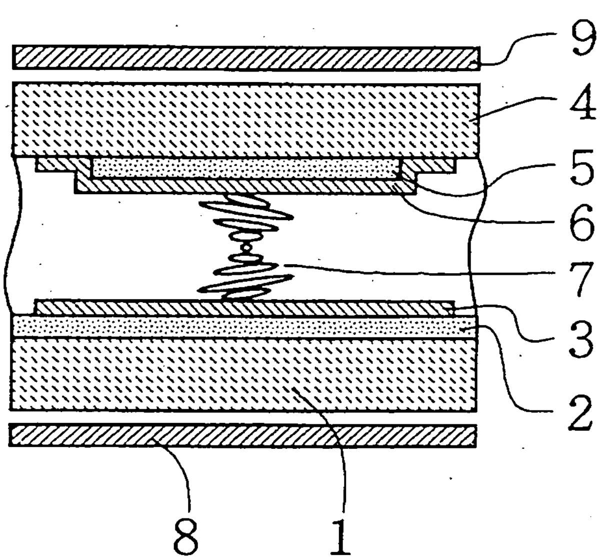
Tf frame term

[NAME OF DOCUMENT] DRAWINGS

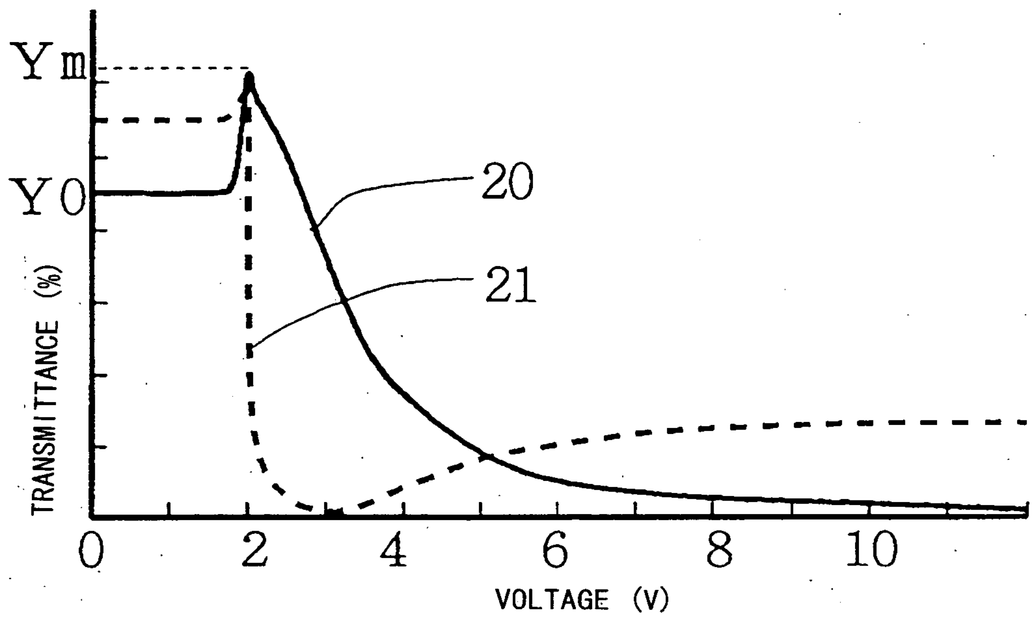
[Fig. 1]



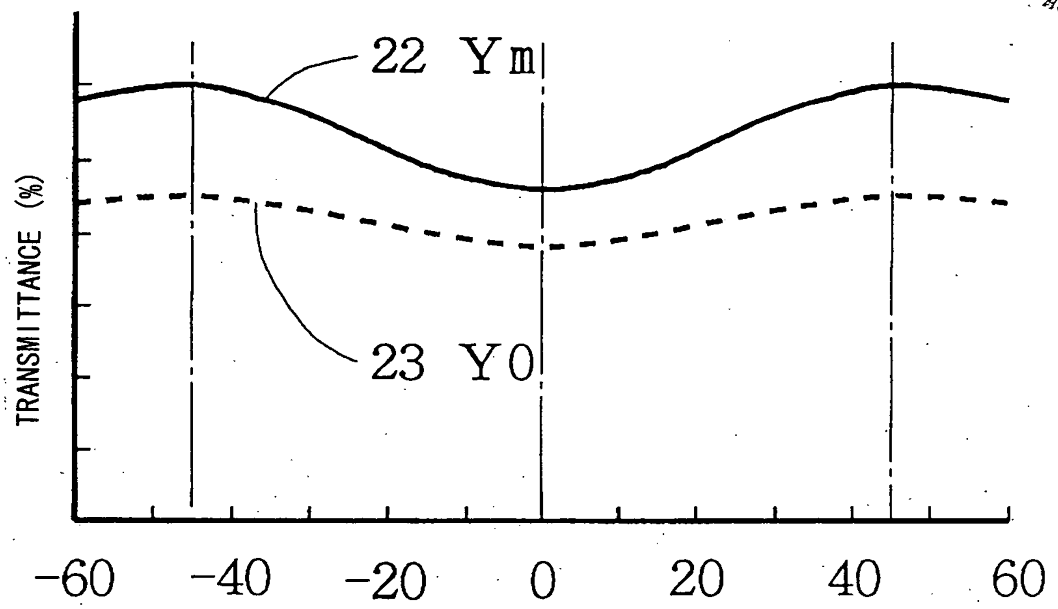

[Fig. 2]



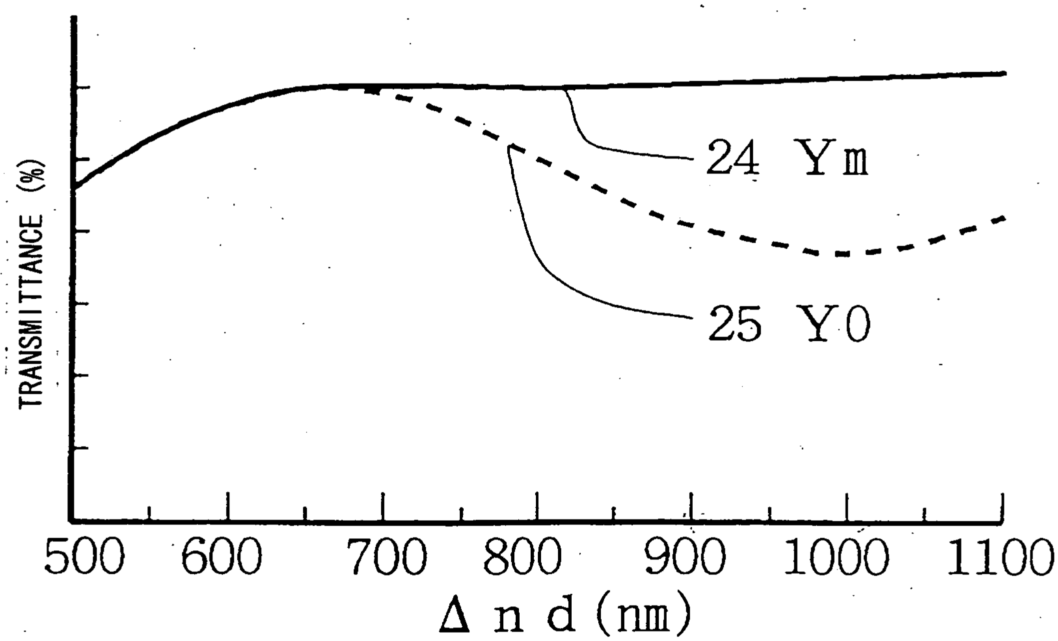
[Fig. 3]



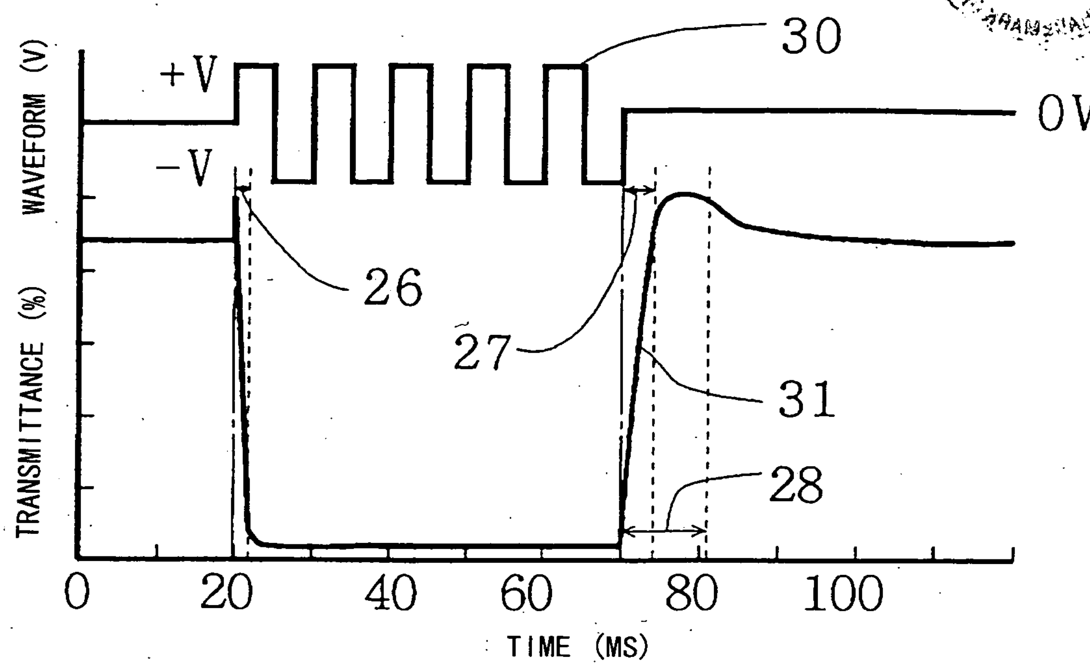
[Fig. 4]


22 Ym
23 Y0
TRANSMITTANCE (%)
-60
-40
-20
0
20
40
60
ARRANGEMENT ANGLE OF POLARIZING PLATE (°)

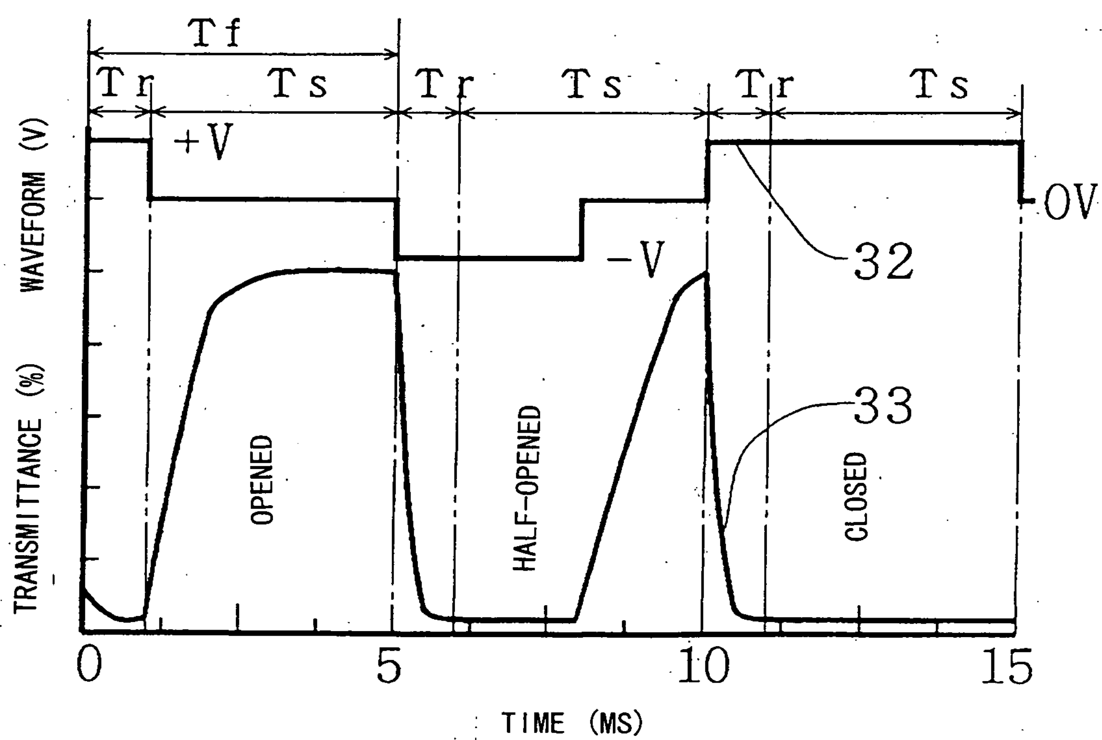
[Fig. 5]


24 Ym
25 Y0
TRANSMITTANCE (%)
500
600
700
800
900
1000
1100
Δ n d (nm)

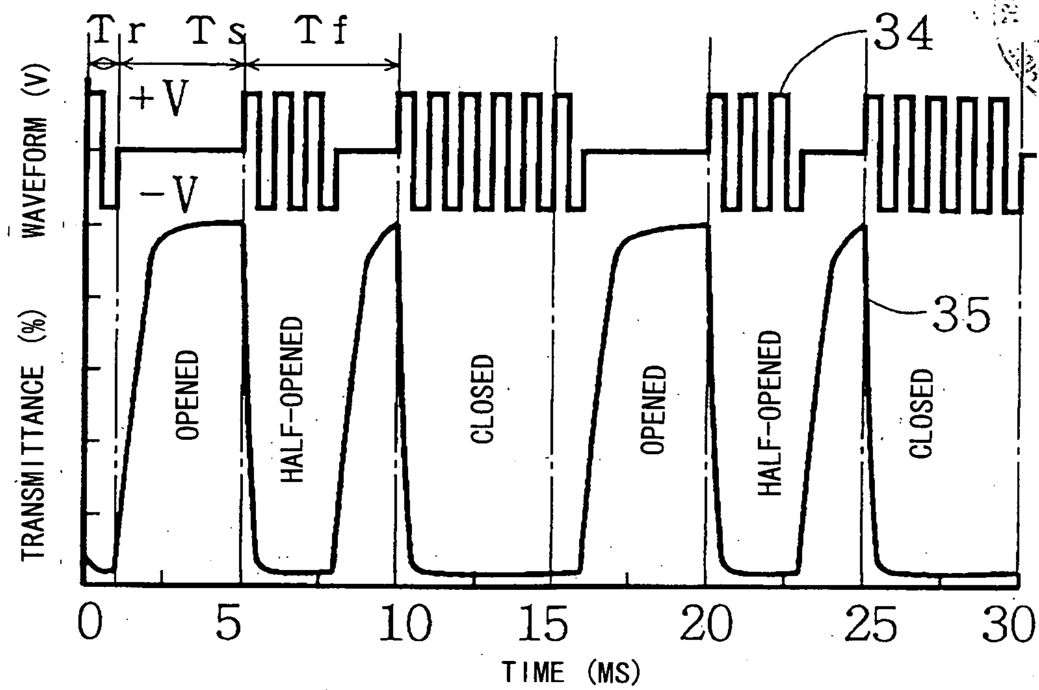
[Fig. 6]


30
+V
0V
-V
WAVEFORM (V)
TRANSMITTANCE (%)
26
27
31
28
0
20
40
60
80
100
TIME (MS)

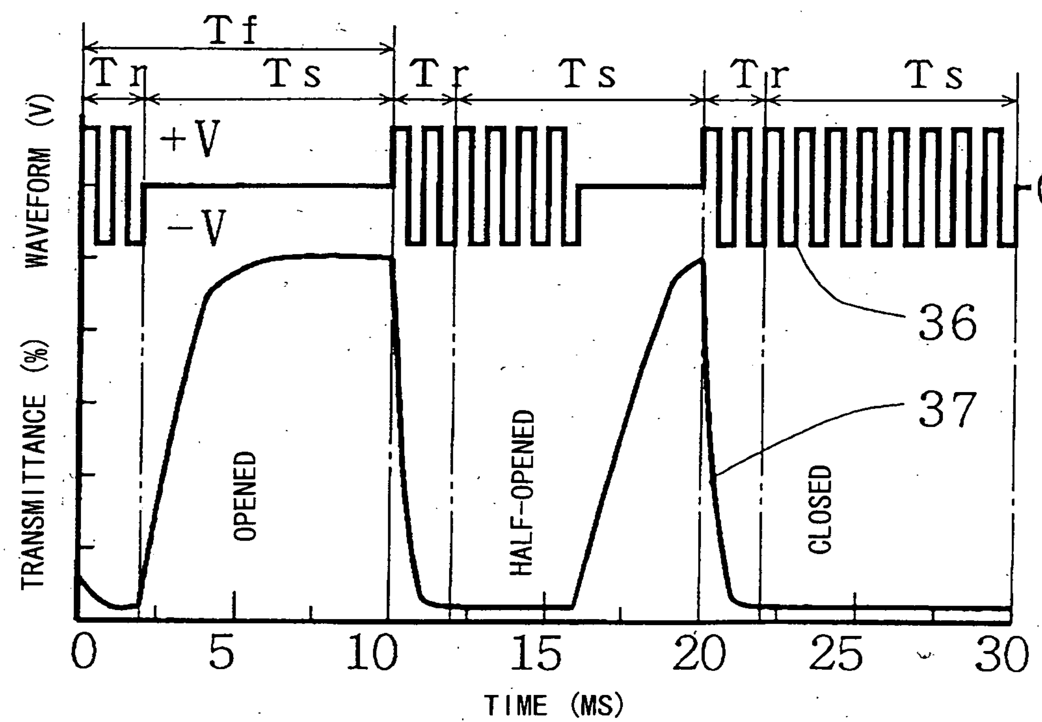
[Fig. 7]


Tf
Tr
Ts
Tr
Ts
Tr
Ts
+V
0V
-V
32
33
WAVEFORM (V)
TRANSMITTANCE (%)
OPENED
HALF-OPENED
CLOSED
0
5
10
15
TIME (MS)

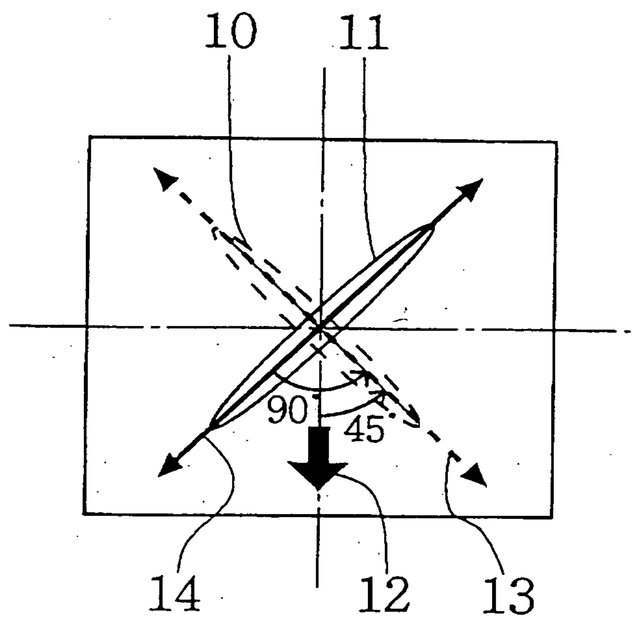
[Fig. 8]


Tr
Ts
Tf
34
+V
−V
0V
WAVEFORM (V)
TRANSMITTANCE (%)
OPENED
HALF-OPENED
CLOSED
OPENED
HALF-OPENED
CLOSED
35
0
5
10
15
20
25
30
TIME (MS)

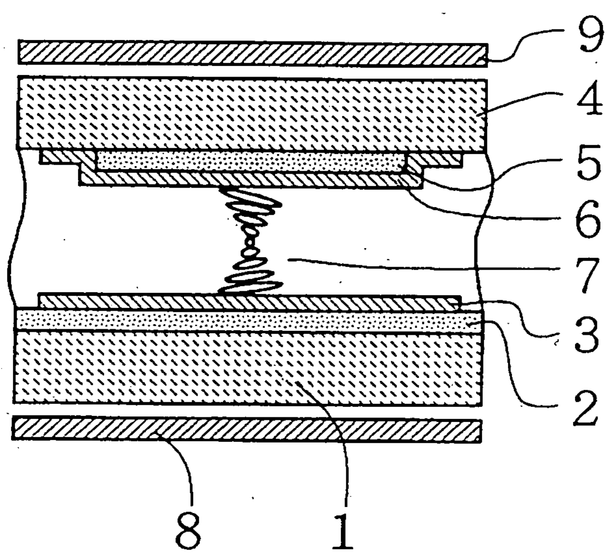
[Fig. 9]


Tf
Tr
Ts
Tr
Ts
Tr
Ts
+V
−V
0V
WAVEFORM (V)
TRANSMITTANCE (%)
36
37
OPENED
HALF-OPENED
CLOSED
0
5
10
15
20
25
30
TIME (MS)

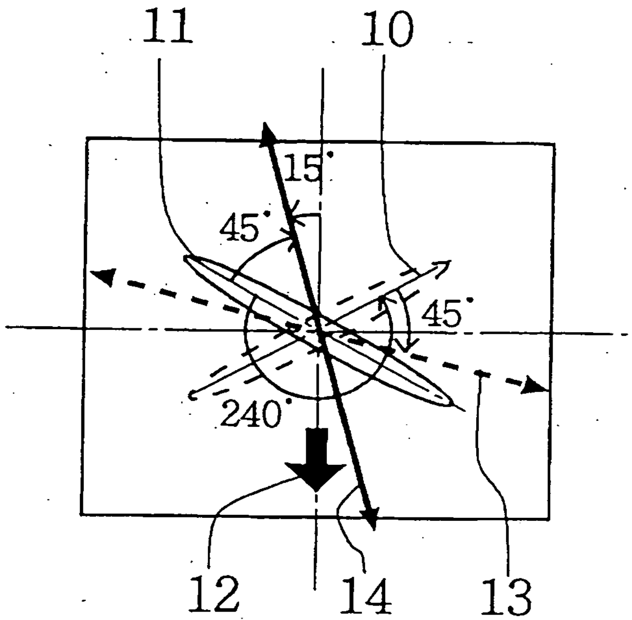
[Fig. 10]



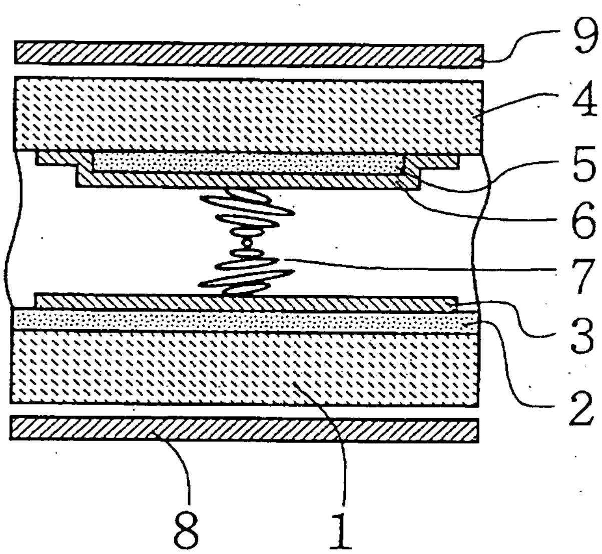

[Fig. 11]



[Fig. 12]




[Fig. 13]



[NAME OF DOCUMENT] ABSTRACT

[SUMMARY]

[PURPOSE] A liquid crystal shutter ensuring a rapid response and a high contrast, and a method of driving the liquid crystal shutter by which a gradation display can be performed.

[CONSTITUTION] In a liquid crystal shutter constituted such that polarizing plates whose absorption axes are orthogonal to each other are disposed outside a liquid crystal device having a twist angle of equal to or greater than 180°, an absorption axis 13 of the lower polarizing plate is arranged at ±45° relative to the direction 12 in which intermediate liquid crystal molecules are oriented, or Δnd of the liquid crystal device is set in a range of 600 to 900 nm.

[SELECTED DRAWING] Fig. 1